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Bursting effects in prestressed concrete sleepers at different prestressed levels

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Abstract. The railway sleeper is an important part of the railway track system, which distributes the wheel load to the substructure. The prestressed concrete sleeper is the most commonly used type around the world, which is usually designed for 50 years of service life. Prestressed concrete sleepers experience various environmental and loading conditions. Meanwhile, the material properties degrade with time. The premature failures of prestressed concrete sleepers could happen and result in a series of problems especially cracking. Tensile strength of prestressed concrete sleeper is much lower than compressive strength like other concrete structures. During service, impact loads could cause cracking in rail-seat or centre area of a prestressed concrete sleeper. Therefore, it is important to understand tensile stress at different prestressed levels. This paper presents a tensile stress assessment method for prestressed concrete sleepers. The outcomes of this paper will improve the concrete sleeper maintenance and inspection criteria.

Keywords: Railway infrastructures; Prestressed concrete; Bursting effects; Tensile stress; cracking.

1. INTRODUCTION

Nowadays, railway is believed the safest form of transportation for either passengers or goods, which provides the safe, economical, and comfort ride of trains (Remennikov et al., 2012). Conventional railway track (also called ‘ballasted railway track’) can be divided into two main parts: superstructure and substructure. Superstructure consists of rails, rail pads, prestressed concrete sleepers, fastening systems. Substructure includes ballast, sub-ballast, and formation (subgrade). The typical conventional railway track structure is illustrated in Figure 1.

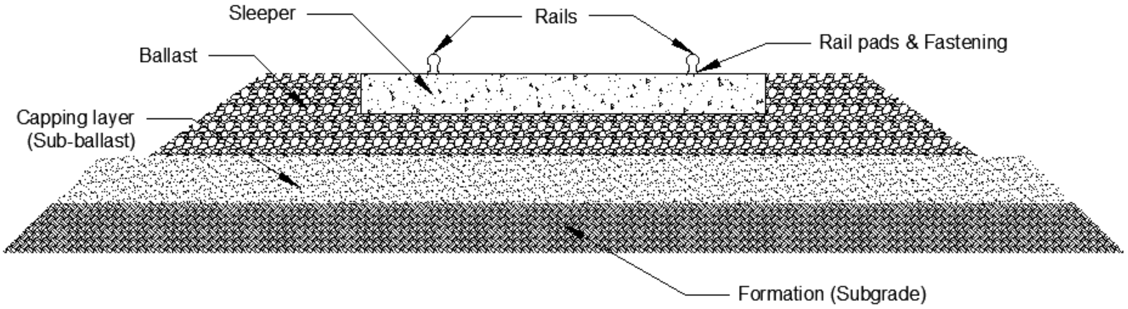


Figure 1. Typical conventional railway track

Railway sleepers (or called 'railroad ties') are the main component of railway track structures (Gustavson, 2004; Kaewunruen & Remennikov, 2009a, 2009b; Kaewunruen et al., 2014; Remennikov & Kaewunruen, 2007; Remennikov et al., 2012). Concrete sleepers can be seen as concrete transverse beam laying on ballast. Railway sleepers can also be manufactured using timber and steel. However, prestressed concrete sleepers are the most commonly used type because of their high load carrying capacity, stability, and low maintenance costs.

In general, the life span of prestressed concrete sleepers is designed to be 50 years. However, many prestressed concrete sleepers do not reach their expected life span due to damage or deterioration (Remennikov & Kaewunruen, 2014; Thun, 2006). The most critical problems related to concrete sleepers worldwide are ranked in Table 1 according to a survey conducted by Van Dyk (Van Dyk et al., 2012). It is obvious that cracking from dynamic loads is a significant problem in concrete sleepers. Cracking in prestressed concrete sleepers is usually caused by impact loads (Murray & Cai, 1998). When trains run at high speed and with heavy haul, the rail-wheel interactions can induce much higher magnitude of loads than simple quasi-static loads (Remennikov & Kaewunruen, 2008). The typical magnitude of impact loads can vary between 100kN and 750kN. The midspan and rail-seat section of railway sleepers are the most likely sections for cracking to occur (Montalbán Domingo et al., 2014).

This paper aims to investigate the crack behaviour of prestressed concrete sleepers. The tensile stresses inside prestressed concrete sleepers at midspan is analysed. In this paper, a numerical study is rigorously executed to comprehensively assess the structural performance of prestressed concrete sleepers. The finite element sleeper model was developed and validated by the capacity experiment (Jing et al., 2021; Li et al., 2021).

Table 1. Most critical causes of concrete sleeper failures (ranked from 1 to 8, with 8 being the most critical)

Main causes	Problems	Worldwide response
Lateral load	Abrasion on rail-seat	3.15
	Shoulder/fastening system wear or fatigue	5.5
Vertical dynamic load	Cracking from dynamic loads	5.21
	Derailment damage	4.57
	Cracking from centre binding	5.36
Manufacturing and maintenance defects	Tamping damage	6.14
	Others (e.g., manufactured defects)	4.09
Environmental considerations	Cracking from environmental or chemical degradation	4.67

2. NUMERICAL MODEL

2.1. Fracture Analysis and Methods

Cracks happen in a component due to imperfections. These imperfections can result from inclusions, grain boundary mismatches, differential thermal expansion or any other mechanisms. The growth of a crack throughout the volume of the structure could result in failure.

In crack simulations, fracture toughness replaces the material strength in fracture calculations. The stress intensity factor (SIF) which determines the fracture toughness subject to linear-elastic fracture mechanics (LEFM) is a function of the stress on the flaw, flaw size, and structural geometry. The stress intensity factor can be calculated by:

$$K_{IC} = \sigma\beta\sqrt{\pi\alpha} \tag{1}$$

where σ is the applied stress; β is the dimensionless correction factor dependent on specimen geometry; and α is the crack length.

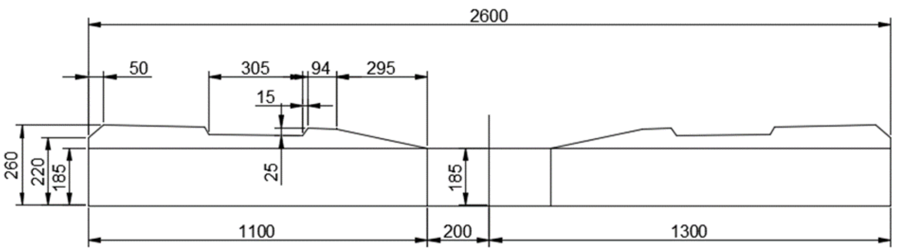
2.2. Crack Simulation Methods

The extended finite element method (XFEM) is often used in fracture simulation, without updating the mesh, instead of traditional cohesive zone modelling (CZM) (Bergara et al., 2017). The extended finite element method eliminates the need for remeshing crack tip regions and it defines an extended finite element enrichment area around a crack tip and in regions where it is plausible that the crack tip might grow (Ansys, 2018). In this way, a finer mesh is created by splitting existing cells instead of remeshing. However, the enrichment area usually takes a long time to compute, and so in large projects with large enrichment areas, the simulation becomes very slow.

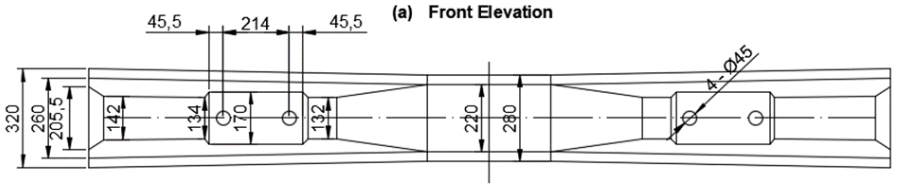
The new Unstructured Mesh Method (UMM) in Ansys mechanical was introduced to generate mesh on crack fronts. With the Unstructured Mesh Method, all-tetrahedral mesh for crack fronts can be generated automatically which reduces pre-processing time. Based on the Unstructured Mesh Method, the Separating Morphing and Adaptive Remeshing Technology (SMART) crack growth simulation was developed. This method automatically updates the mesh according to crack-geometry changes due to crack growth at each solution step instead of using the enrichment area derived from XFEM (Ansys, 2018; Kulakov et al., 2021). The SMART crack simulation can be applied in large projects, unlike XFEM.

2.3. Finite Element Sleeper Model

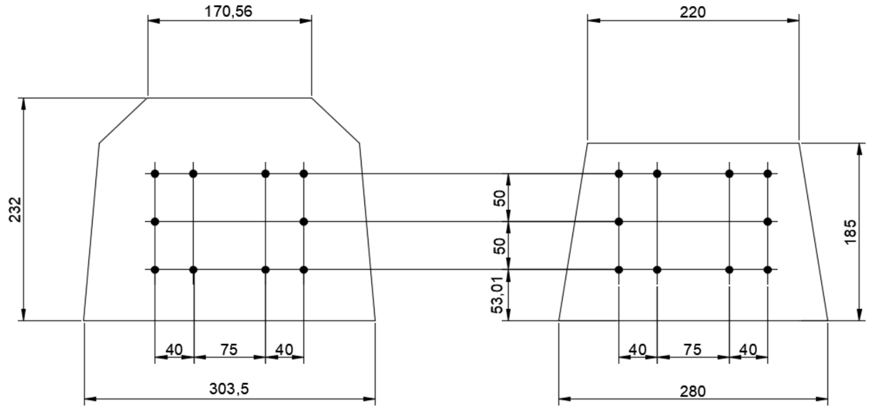
In this paper, a 2600-mm long Chinese Type III prestressed concrete sleeper with 7mm diameter tendons (Figure 2) is utilised in the crack simulation. This type of railway sleeper, which is an integrated concrete block using pre-tensioning technology, is widely used in China. The material properties are shown in Table 2. Modelling is performed a model which is as close to the actual sleeper as possible.



(a) Front Elevation



(b) Plan



(c) Rail seat Section (d) Midspan Section

Figure 2. Geometrical features of the prestressed concrete sleeper

Table 2. Material properties of the prestressed concrete sleeper

Material properties	Basic variables	Value
Concrete	Mean compressive strength	65MPa
	Modulus of elasticity	33GPa
Prestressed wire	Yield strength	1570MPa
	Modulus of elasticity	200GPa
	Prestressing force	420kN

2.4. Crack Model

An experimental study investigated crack propagation in the Chinese Type III prestressed concrete sleeper. The static capacity test of the railway sleeper was executed in accordance with EN 13230-2 (Standardization, 2009). Using the experimental procedure, the crack propagation of prestressed concrete sleepers under capacity experiment is simulated. Figure 3 presents the simulation of crack propagation in the sleeper model at midspan.

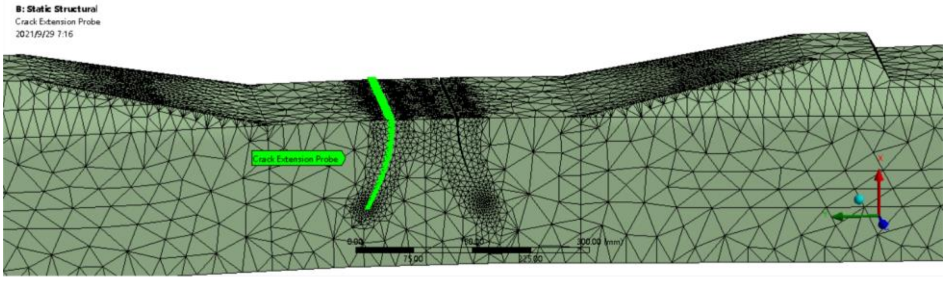


Figure 3. Simulation of crack propagation in the sleeper model at midspan

The comparison of the numerical and experimental results on crack propagation is presented in Figure 4. Numerical model basically simulated the crack propagation in comparison with the experimental results. In the simulation, the numerical model has a good correlation with the initial crack point and ultimate crack point, with the difference being only 6.31% and 4.34% respectively.

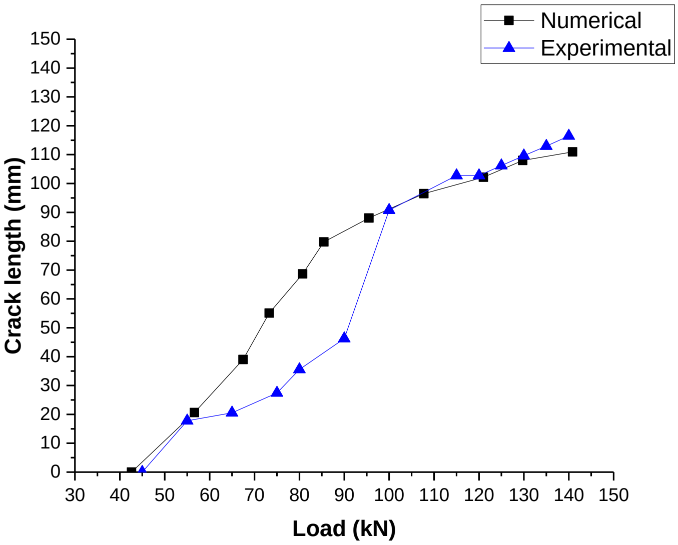


Figure 4. Comparison of the crack propagation in the numerical and experimental results

3 RESULTS AND DISCUSSION

Using the crack model in section 2, the tensile stresses of the prestressed concrete sleeper can be illustrated in Figure 5 for crack propagation at midspan. Figure 5 presents the bursting effects of prestressed concrete sleepers at midspan.

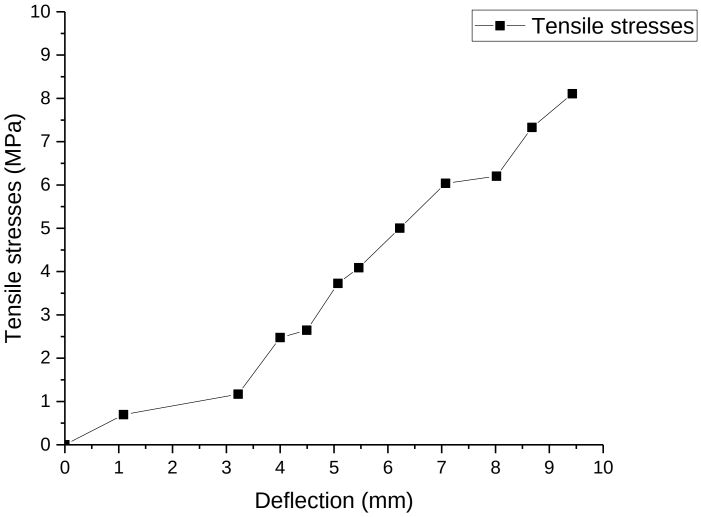


Figure 5. Tensile stresses of prestressed concrete sleepers

4 CONCLUSIONS

Cracking from dynamic loads at midspan is one of the most common forms of railway sleeper damage in conventional tracks. The challenge for railway engineers is to improve the performance of railway sleepers to fulfil crack resistance requirements. In this study, numerical and experimental investigations into the bursting effects of prestressed concrete sleepers were conducted. A full-scale model of Chinese Type III prestressed concrete sleepers was modelled and validated. The outcome of this paper will enhance the reliability and safety of track components, and railway sleeper manufacturers could use the numerical model to assess their product designs.

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Infrastructure Systems Engineering Network" (www.risen2rail.eu) [39]. In addition, the first author wishes to thank the China Academy of Railway Science (CARS) for the collaborative project.

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